SIDLEY AUSTIN LLP
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SIDLEY AUSTIN LLP
1501 K STREET, N.W.
WASHINGTON, D.C. 20005
(202) 736 8000
(202) 736 8711 FAX

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WASHINGTON, D.C.

dlawson@sidley.com
(202) 736 8088

FOUNDED 1866

May 7, 2014

REDACTED – FOR PUBLIC INSPECTION

By ECFS

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Re: *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268; *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269

Dear Ms. Dortch:

On behalf of AT&T, please find attached one redacted copy of an AT&T *ex parte* to be filed in the above-captioned proceedings. The highly confidential version of the attached letter contains information that has already been designated as "highly confidential" by T-Mobile, as well as additional information that is being designated by AT&T as "highly confidential," under the Protective Order in the above-captioned proceedings.[1] Pursuant to the Protective Order, one copy of the highly confidential version of the attached letter will be submitted to the Secretary's Office, and two copies of the highly confidential version of the attached letter will be delivered to William Beckwith of the Spectrum and Competition Policy Division of the Wireless Telecommunications Bureau.

[1] Protective Order, *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268; *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269 (rel. March 27, 2014) ("Protective Order").

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Sincerely,

/s/ *David L. Lawson*
David L. Lawson

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SIDLEY AUSTIN LLP

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1501 K STREET, N.W.
WASHINGTON, D.C. 20005
(202) 736 8000
(202) 736 8711 FAX

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Re: *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, GN Docket No. 12-268; *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269

Dear Ms. Dortch:

AT&T submits this letter in response to recent filings by Sprint and T-Mobile.[1] In those submissions, Sprint and T-Mobile continue to seek special regulatory preferences that would allow them to more easily acquire sub-1 GHz spectrum while placing artificial limits on the ability of AT&T or Verizon to acquire such spectrum. Instead of allowing spectrum to flow to its most valued uses through fully open auctions and secondary marketplace transactions, they ask the Commission to establish spectrum aggregation policies based on *regulatory* determinations of the "value" or "utility" of different spectrum frequencies derived solely from their propagation characteristics and what those characteristics may imply for the cost of deploying cell sites.

[1] *See* Lawrence R. Krevor *et al.*, *The Imperative for a Weighted Spectrum Screen: Low-, Mid-, and High-Band Frequencies Are Not Freely Substitutable Market Inputs*, attached to Letter from Lawrence R. Krevor, Vice President, Sprint Corp., to Marlene H. Dortch, Secretary, Federal Communications Commission, WT Docket No. 12-269 (Apr. 4, 2014) ("*Sprint 4/4/14 Paper*"); *see also* Declaration of Mark McDiarmid, attached to Letter from Trey Hanbury, counsel to T-Mobile USA, Inc., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268 & WT Docket No. 12-269 (Apr. 1, 2014) ("McDiarmid Decl.").

The Sprint and T-Mobile analyses are conceptually flawed, contrary to fundamental wireless engineering principles, and refuted by real-world empirical evidence. Their analyses depend on unrealistic assumptions, ignore a host of other important determinants of the value of spectrum that cut the other way, and inevitably would be far more arbitrary and indefensible than marketplace valuations of the same spectrum as determined in auction and secondary transactions. Indeed, these new submissions vividly illustrate the inherent arbitrariness of such an approach: Sprint, in response to prior criticisms, has now modified its analysis of deployment costs to account for additional variables and as a result it has reduced its estimate of how much more a provider of 2.5 GHz spectrum would have to spend to deploy a suburban network than a provider of 700 MHz from *seven times* to *1.9 times*. And just last week, Sprint again modified its proposal, now claiming that the Commission could defend arbitrary 1.5, 1.0, and 0.5 weightings of "low", "mid" and "high" frequency spectrum, respectively that would count AT&T's 700 MHz and 850 MHz cellular spectrum three times as much as Sprint's 2.5 GHz spectrum.[2] Such wild swings in Sprint's own calculations and proposals reflect the arbitrariness of Sprint's assumptions and results-oriented methods, not any underlying competitive reality.

As explained below and in the accompanying supplemental declaration of Drs. Reed and Tripathi, (1) neither Sprint nor T-Mobile has answered the fundamental point that their entire propagation-based approach is inconsistent with basic principles of economics; (2) both Sprint's and T-Mobile's studies are fundamentally flawed even on their own terms, and would not support regulatory preferences based on differences in deployment costs; and (3) the regulatory preferences they seek would harm the public interest.

Basic Economics. As AT&T has previously explained, any attempt to adopt spectrum aggregation policies that treat spectrum frequencies differently based on their propagation characteristics and deployment costs would ignore fundamental principles of economics and thus would be arbitrary. Sprint and T-Mobile's analyses focus on one characteristic of spectrum – propagation – and how that characteristic affects one aspect of a provider's costs – its cost to deploy cell sites. The total economic costs of deploying a network, however, include the cost of *both* cell-site deployment *and* the underlying spectrum licenses. Focusing only on deployment costs and ignoring spectrum costs is a basic mistake in economic reasoning. That is especially so in this context, because as the economic testimony in this proceeding establishes, even if it were always true that high-band spectrum costs more to deploy, those higher deployment costs, like all other factors that affect the competitive value of spectrum, will be reflected in the spectrum license costs. If some spectrum will cost more to deploy, then, all else equal, it will sell for lower prices at auction or in secondary market transactions, and the two effects will largely offset one another.

[2] *See* Letter from Gardner H. Foster, Senior Counsel, Sprint Corp., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268 & WT Docket No. 12-269 (May 1, 2014).

T-Mobile completely ignores this dispositive point. Sprint at least grapples with the issue, but it has no answer. In fact, Sprint starts by agreeing with our most basic contention, which is that the only valid purpose of the Commission's spectrum aggregation policies is to identify transactions that actually threaten market *foreclosure* – or, as Sprint puts it, to "[a]nalyz[e] whether a particular acquisition undermines the ability of competing firms to enter the mobile broadband market or expand output swiftly and effectively in response to another firm's attempt to exercise market power."[3] As AT&T has explained in detail, no provider in today's wireless marketplace would have any hope of amassing enough spectrum (regardless of frequency) to achieve either of these objectives, and Sprint has provided no evidence to the contrary.[4]

Sprint's new trope is that high- and low-frequency spectrum are not "substitutable," but that is plainly not correct. There is no dispute that either high- or low-frequency spectrum can be used to provide mobile wireless services. Indeed, there could be no such dispute, because Sprint and T-Mobile today are both using high-frequency spectrum to offer LTE services (and T-Mobile, relying *entirely* on high-frequency spectrum, had more net additions last quarter than AT&T and Verizon combined).[5] Since an operator can use any of these spectrum frequencies to offer mobile wireless service and win customers, any of these frequencies can be substituted to defeat attempts at market foreclosure. Accordingly, all of the available spectrum frequencies – whether they are called "high," "mid," or "low" – are unambiguously *substitutable* for the only purpose relevant to the Commission's spectrum aggregation policies. To be sure, each frequency band may have some unique characteristics that could affect the precise manner in which an operator will choose to deploy its network and the cost it may incur in doing so, but those differences do not affect the ability of Sprint or T-Mobile (each of which already operates an expansive network specifically designed to make efficient use of high-frequency spectrum) to expand output effectively in response to another firm's attempt to exercise market power.

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[3] *See* "The Commission's Mobile Spectrum Holdings Policies: Aligning the Screen with Its Original Purpose" at 2, attached to Letter from Gardner H. Foster, Senior Counsel, Sprint Corp., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268 & WT Docket No. 12-269 (Apr. 7, 2014).

[4] Comments of AT&T Inc., WT Docket No. 12-269, at 13-21 (Nov. 28, 2012); Reply Comments of AT&T Inc., WT Docket No. 12-269, at 8-13 (Jan. 7, 2013).

[5] Scott Moritz and Amy Thompson, "T-Mobile Adds More Customers Than AT&T, Verizon Combined," Bloomberg.com (May 1, 2014), available at http://www.bloomberg.com/news/2014-05-01/t-mobile-lures-1-3-million-contract-customers-in-first-quarter.html; T-Mobile Press Release, "T-Mobile US Reports First Quarter 2014 Results and Best Ever Quarterly Performance in Branded Postpaid Net Customer Additions," available at http://investor.t-mobile.com/file.aspx?IID=4091145&FID=23437708 (May 1, 2014).

Both Sprint and T-Mobile now appear to be claiming that all providers need at least *some* low-frequency spectrum to provide a "coverage layer," and that the Commission should therefore create regulatory preferences to ensure that Sprint and T-Mobile have an enhanced opportunity to acquire such spectrum. Even if that were true, however, both Sprint and T-Mobile *already have* such low-frequency coverage layers. T-Mobile recently purchased what it describes as a "huge swath" of 700 MHz A-Block spectrum from Verizon, which covers 70 percent of T-Mobile's customer base,[6] and its senior management has made clear that T-Mobile has "a whole host of solutions" for acquiring additional low-frequency spectrum in secondary markets.[7] Similarly, Sprint has already announced that it will use its 800 MHz spectrum as the low-frequency spectrum foundation of its Sprint Spark service, which "will work via the combination of its 800 MHz, 1.9 GHz and 2.5 GHz LTE spectrum."[8] There is simply no economic basis for the Commission to structure its spectrum aggregation or auction rules to give Sprint or T-Mobile an artificial advantage in acquiring additional low-frequency spectrum.

Sprint and T-Mobile's Deployment Cost Analyses. Even if it were appropriate to base spectrum aggregation policies solely on propagation characteristics and deployment costs, neither Sprint nor T-Mobile has justified a rule or policy in which the Commission would treat low-frequency spectrum differently.

(1) Sprint's Reply.

Urban Deployment Costs and In-Building Penetration. In its prior submission, Sprint conceded that deployments in urban areas were capacity-driven rather than coverage-driven, but it claimed that providers using high-frequency spectrum still needed to deploy *three times* as many macrocell sites in urban areas to achieve the same level of in-building penetration as a provider using low-frequency spectrum. That figure was implausible on its face and Drs. Reed

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[6] Remarks of Neville Ray, Chief Technology Officer, T-Mobile USA, Inc., Morgan Stanley Technology, Media & Telecom Conference (Mar. 5, 2014), at 3.

[7] Remarks of Neville Ray, Chief Technology Officer, T-Mobile USA, Inc., Deutsche Bank Media, Internet & Telecom Conference (Mar. 10, 2014), at 9 (stating that T-Mobile has "a whole host of solutions" for expanding its low-frequency coverage, including acquiring additional 700 MHz licensees on the secondary market).

[8] Phil Goldstein, *Sprint Spark to combine LTE in 800 MHz, 1.9 GHz and 2.5 GHz, will offer 50-60 Mbps peak speeds*, FierceWireless (Oct. 30, 2013), http://www.fiercewireless.com/story/sprint-spark-combine-lte-800-mhz-19-ghz-and-25-ghz-will-offer-50-60-mbps-pe/2013-10-30#ixzz2z0BbdEpU.

and Tripathi demonstrated that Sprint's analysis was incorrect.[9] Sprint has made no attempt to defend its three-to-one calculation in response, and that is likely due to the fact that, if Sprint were to make the same sorts of adjustments to its urban analysis that it has now made to its suburban and rural analyses, it could no longer support any "weighting" factor at all for urban areas.[10] The Commission should therefore consider Sprint to have abandoned the argument as to urban areas and recognize that there is no record basis to treat low-frequency spectrum differently in urban areas.

Sprint merely tries to defend the general idea that low-frequency spectrum penetrates buildings better than high-frequency spectrum.[11] But as Sprint itself concedes, it depends. For the "steel and reinforced concrete construction" that dominates downtown urban areas, Sprint *agrees* with Drs. Reed and Tripathi (and the sources that Sprint itself originally cited) that building penetration will depend on "the type of building material and also on the presence, size, and orientation of windows."[12] As Sprint acknowledges, "[l]osses through windows are very frequency selective" – the lower the frequency, the more likely it is to lose penetration.[13] These points confirm AT&T's conclusions: all providers must deal with penetration loss in steel and

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[9] *See* Jeffrey H. Reed & Nishith D. Tripathi, *The Value of Spectrum: A Further Response to Sprint's Paper "The Imperative for a Weighted Spectrum Screen,"* at 12-13 (attached hereto as Attachment A) ("Reed/Tripathi Decl.") ("We demonstrated that the assumptions underlying [Sprint's] analysis of urban deployments were incorrect for a number of reasons, including that it significantly overstates building penetration differences for high- and low-frequency spectrum, erroneously focuses on absolute in-building signal levels rather than SINR, fails to account for the offsetting frequency-specific characteristics that give high-frequency spectrum in-building advantages, and fails to account for widespread and increasing use of small cell and other technologies used to address in-building performance in modern networks.").

[10] *Id.* at 13.

[11] *Sprint 4/4/14 Paper* at 22-23.

[12] *Id.* at 23.

[13] *Id.* at 23; *see also* Communications Research Centre Canada, *Comparison of Radio Propagation Characteristics at 700 and 2,500 MHz Pertaining to Macrocellular Coverage* (Apr. 2011), at 24-25 ("[These urban buildings] are often of steel-framed construction, and the corresponding predominant building materials are reinforced concrete, steel, and aluminum; loss through these materials is relatively much higher, and the dominant penetration mode is through slots such as windows and other frame openings, or even through grid openings in steel-reinforced concrete slabs. Losses associated with propagation through slots tend to be strongly frequency-selective, and overall decrease with increasing frequency, as the slot dimensions become larger in terms of the wavelength").

reinforced concrete buildings, but high-frequency spectrum has the advantage in penetrating such buildings because it is more likely to penetrate the windows. Sprint also asserts that low-frequency spectrum suffers fewer building penetration losses in residential buildings, but again, the study that Sprint cited explains that high- and low-frequency spectrum penetrate the types of materials typically used for residential buildings equally well (except for red brick and cinder block buildings, where lower-frequency spectrum has the advantage).[14]

As AT&T also showed, a real-world operator would typically address in-building penetration issues with in-building and small cell deployments (such as DAS, femtocells, WiFi, etc.), not the far more expensive approach of tripling the number of macrocell sites. Sprint claims that its prior submission "acknowledges that in-building coverage can also be improved through the use of femtocells and picocells that can be installed indoors or in areas immediately adjacent to buildings,"[15] but the fact is that Sprint's previous three-to-one weighting calculation depended directly on the assumption that an operator would address in-building penetration issues by deploying macrocell sites – an analysis that, as noted above, Sprint has now essentially abandoned. Sprint now asserts (without any evidence) that there would be too many buildings to serve with small cells for any such deployment to be cost-effective.[16] As the engineering testimony in this proceeding establishes, however, due to the large number of cell sites needed in urban and suburban areas to meet capacity demands, urban buildings will typically be close enough to a cell site that they can be adequately penetrated by high- or low-frequency signals. As a result, the potential "problem" buildings are likely to be a relatively small subset of buildings nearer to the cell edge (or obstructed), and in those cases, network operators use efficient in-building solutions, such as the deployment of femtocells, DAS and other small-cell solutions, not a costly doubling or tripling of macrocell sites, as Sprint assumes.[17]

Finally, AT&T showed that Sprint's central contention – that a carrier relying on high-frequency spectrum must construct many more cell sites – cannot be squared with the real-world facts. Drive-test data that AT&T uses in the ordinary course of business show that AT&T, Sprint, and T-Mobile all have cell densities that are roughly *equal* in CMAs of greatly varying population density. In fact, AT&T has *more* cell sites than Sprint in almost all of the top 100 CMAs (and more than T-Mobile in about half of those). Where Sprint and T-Mobile do have more cell sites, they typically have 20 to 30 percent more, not many times more, as the frequency-based screen proposals would predict. The Commission could not lawfully treat low-

[14] *Sprint 4/4/14 Paper* at 22; Reed/Tripathi Decl. at 13-14.

[15] *Sprint 4/4/14 Paper* at 23 (internal citation omitted).

[16] *Id.* at 23-24.

[17] *See* Reed/Tripathi Decl. at 16-17.

frequency spectrum as having special "value" in its spectrum aggregation analysis based on an assumed advantage in cell-site deployment, when there is no such advantage in the real world.

Sprint suggests that AT&T may have more cell sites than Sprint because AT&T has more extensive geographic coverage than Sprint, but it provides no evidence no support that claim.[18] To the contrary, Sprint tries to change the subject – it pivots to a comparison of *nationwide* coverage maps in an attempt to show that AT&T's coverage areas are larger.[19] But AT&T's evidence was focused on the 100 largest CMAs (which account for nearly two-thirds of the U.S. population), where Sprint has operated for more than a decade and almost certainly has few significant coverage gaps. Indeed, as Drs. Reed and Tripathi explain, the drive-test data specifically show that AT&T has more cell sites than Sprint in each of the top *ten* CMAs, and Sprint's online coverage maps appear to blanket those CMAs.[20]

Suburban and Rural Deployment Costs. AT&T also showed previously that Sprint's analysis of deployment costs in suburban and rural areas was incorrect. Although Sprint argued that deployments in such areas would be coverage-driven, AT&T showed that Sprint in fact was defining "suburban" to include many densely populated census block groups where deployments would clearly be driven by capacity, not coverage. Sprint then used a flawed, "simplified" path loss propagation model to determine how many cell sites would be required in a coverage-driven deployment in these areas, and concluded that a 2.5 GHz deployment would require seven times as many cell sites as a Lower 700 MHz deployment in suburban areas and fourteen times as many in rural areas. These figures, too, were implausible on their face, and AT&T demonstrated, using the RF planning and design software that AT&T uses in the ordinary course of business to design and engineer radio networks, that Sprint had grossly overstated the number of additional cell sites that would be needed in a truly coverage-driven and greenfield 2.5 GHz deployment.

Sprint's latest analysis does not fix *any* of these fundamental flaws – it still relies on the same overbroad definitions of suburban and rural areas and the same flawed propagation model.[21] Retaining these facially implausible estimates as a baseline, Sprint now attempts to add

[18] *Sprint 4/4/14 Paper* at 25.

[19] *Id*.

[20] *See* Reed/Tripathi Decl. at 21-22.

[21] Sprint argues that changing how it defines "suburban" would make no difference, but as Sprint's own chart shows, if it changed the threshold for suburban from 10,000 people per square mile to 1,000 (the threshold used by the U.S. Census Bureau), that change alone would reduce Sprint's estimate of the number of additional cell sites needed *by half* – eliminating entirely the 1.9 times cost difference Sprint now claims for suburban deployment. Reed/Tripathi Decl. at 19.

in the offsetting effect of spectrum license costs. Even by Sprint's skewed calculations, the results are dramatic: Sprint previously estimated that a provider would have to spend seven times as much to deploy 2.5 GHz network in a suburban area as it would for a Lower 700 MHz network, but now it says it would only need to spend less than two times as much.[22]

But the figures Sprint is using as spectrum costs are themselves artificial constructs that are not reliable. For example, for its suburban analysis, the SR Paper assumes that spectrum licenses for Lower 700 MHz spectrum cost only $2.00/MHz-POP. As explained above, however, the SR Paper's definition of "suburban" extends to areas with a population density up to 10,000 people per square mile, which includes many unambiguously urban areas in major cities. As AT&T previously demonstrated in this proceeding, even for areas with population densities of between 618-4290 people per square mile, Lower 700 MHz spectrum in Auction 73 sold for more than $4.00/MHz-POP, which is nearly twice the amount that the SR Paper assumes.[23] Sprint thus greatly understates the extent to which spectrum license costs offset potential savings in deployment costs.

The same is true with respect to rural areas, where Sprint estimates the cost of 700 MHz spectrum to be $0.60 per MHz-POP.[24] That figure is quite low compared to the reported prices per MHz-POP for such spectrum in auctions and in recent secondary market transactions.[25] Although Sprint does not explain how it derived estimated spectrum costs, it apparently discounted the prices by some undisclosed method to account for the fact that there is reduced

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With respect to AT&T's RF planning analysis, Sprint claims that AT&T's analysis was "apples-to-oranges" because it modeled a 700 MHz network using a 2x2 transmitter/receiver configuration, an AWS network using a 2x4 transmitter/receiver configuration, and a 2.5 GHz network using a 4x4 transmitter/receiver configuration, with a 30 watt transmitter for each transmit antenna. *Sprint 4/4/14 Paper* at 24-25. AT&T's approach was correct, however, because that is how each of these spectrum frequencies would be deployed in the real world. Ignoring those real-world configurations would provide an inaccurate prediction of the number of cell sites that would have to be deployed for each spectrum frequency. Reed/Tripathi Decl. at 20-21.

[22] *Sprint 4/4/14 Paper* at 12.

[23] *See* Reply Declaration of Mark A. Israel and Michael L. Katz, Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings, ¶ 20-21, attached to Reply Comments of AT&T Inc., *Policies Regarding Mobile Spectrum Holdings,* WT Docket No. 12-269 (Jan. 7, 2013).

[24] *Id.* at 10.

[25] *See* Reed/Tripathi Decl. at 22 ("T-Mobile estimates that recent secondary market transactions for Lower 700 MHz spectrum ranged from about $1.57/MHz-POP up to $4.29/MHz-POP").

demand for spectrum in rural areas. In the real world, however, 700 MHz licenses are available at the EA and CMA levels, which typically cover geographic areas encompassing both rural and non-rural areas, and in the real world operators can acquire such licenses only at prices that are much higher than Sprint assumes.[26]

In short, the Commission could not rationally rely on Sprint's suburban/rural analysis, because each aspect of that analysis – the definition of "suburban" and "rural," the propagation model, and the spectrum cost estimates – is unreliable (and to a large extent remains unexplained). And, of course, Sprint's analysis focuses *only* on propagation and spectrum costs, and continues to ignore many other important determinants of the "value" and "utility" of different spectrum frequencies, as Drs. Reed and Tripathi explain in detail in the attached declaration.[27]

(2) The T-Mobile Study.

T-Mobile's declaration focuses solely on urban areas and in-building penetration issues, and the centerpiece of its submission is a description of an internal "network design study" for Dallas, Texas. As a baseline, T-Mobile starts with a coverage analysis of its AWS network using existing 1.9 GHz facilities, and asserts that such a network provides "excellent outdoor coverage for a high percentage of the population" and indoor coverage that is "less reliable."[28] For the "purpose of comparison," T-Mobile then modeled coverage of the same areas using 700 MHz spectrum and concludes that T-Mobile could achieve better in-building penetration with fewer cell sites.[29] The "study" is largely based upon assertions for which T-Mobile has provided no underlying support.

This analysis, however, does not prove anything relevant to the Commission's spectrum aggregation policies. The only thing the analysis purports to show is that, in *theory*, a provider could build a *coverage*-driven, 700 MHz-only network in Dallas with fewer cell sites than T-Mobile's existing AWS network. But no real-world operator would build any such network in Dallas today or achieve the deployment or other cost savings T-Mobile implies, because T-Mobile's analysis suffers from many of the same fundamental flaws that we previously identified with respect to Sprint's analysis: (1) T-Mobile is focusing on only one characteristic of the spectrum, propagation, and ignoring that any propagation-related differences in deployment costs

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[26] *Id.* at 23.

[27] *See id.* at 18-24.

[28] McDiarmid Decl. ¶ 14.

[29] *Id.* at ¶¶ 15-16.

will be offset by lower prices for the spectrum itself; (2) T-Mobile is also ignoring the fact that deployment in urban/suburban areas like Dallas is driven today by capacity, not coverage, and in such environments cell sizes must be small to achieve the necessary quality of service and throughput, thus negating the theoretical propagation advantages of the low-frequency spectrum[30]; (3) providers today have a mix of high- and low-frequency spectrum, and since operators typically transmit both low- and high-frequency signals from their cell sites, operators engineer their cell sizes to reflect the weaker propagation of high-frequency spectrum, again negating the theoretical deployment advantage of low-frequency spectrum; and (4) high-frequency spectrum has many important characteristics other than propagation, and many of those – including the availability of larger contiguous blocks, reduced inter-cell interference, improved ability to take advantage of advanced antenna capabilities, and the like – give high-frequency spectrum significant countervailing marketplace advantages.

By focusing solely on propagation, T-Mobile misses the bigger picture, and indeed, the drive-test data refute T-Mobile's conclusions. If T-Mobile were correct, then AT&T, which uses 700 MHz spectrum in Dallas, should have far fewer cell sites in Dallas than T-Mobile, which uses AWS spectrum there. In fact, however, the drive tests show that AT&T actually has about 150 *more* cell sites than T-Mobile in the Dallas-Fort Worth CMA. T-Mobile's only answer to AT&T's drive-test data is the general claim that AT&T has more extensive coverage than T-Mobile, but T-Mobile provides no supporting evidence and in fact T-Mobile does not appear to have any significant coverage gaps in the Dallas-Fort Worth CMA.[31]

T-Mobile's study, like Sprint's, also incorrectly assumes that the only way to fill indoor coverage gaps in a network is to deploy additional expensive macrocell sites, rather than deploying far less expensive indoor small cell systems. T-Mobile claims that the use of small cells is not a practical solution because (1) it is more costly and (2) the regulatory permissions needed to deploy such systems are overly onerous. The marketplace evidence refutes the notion that these solutions are too expensive or onerous, because providers have already deployed many thousands of small cells and their use is growing. According to the Small Cell Forum, small cells are being deployed at a rapid pace with the number of small cells having overtaken the total

[30] In fact, far from being a benefit, the propagation characteristics of low-band spectrum can be a significant *disadvantage* in small-cell environments due to the potential for inter-cell interference, a fact that T-Mobile acknowledges. *See* McDiarmid Decl. ¶ 11.

[31] T-Mobile's online coverage map for Dallas is saturated in pink, which indicates that "Voice and high speed data coverage is: Excellent. Get clear calls plus our advanced 4G LTE coverage you'll experience uploads, downloads, streaming, and surfing at our fastest speeds ever." T-Mobile, *Check Coverage*, http://www.t-mobile.com/coverage.html (last visited May 1, 2014).

number of macrocells between October 2012 and November 2012.[32] T-Mobile has touted the significant benefits of DAS systems in terms of indoor coverage and meeting capacity demands in urban areas.[33] As part of its Project VIP expansion AT&T is deploying 40,000 small cells and over a thousand distributed antenna systems ("DAS").

T-Mobile argues that deploying DAS systems (or other small cell solutions) is not cost-effective because "to achieve *coverage equivalent to a macrocell*, the average cost is . . . more than that of a macrocell."[34] But no one is suggesting that DAS systems or small cells need to be deployed to cover an area equivalent to a macrocell; the issue here is attaining coverage within a relatively small percentage of buildings. T-Mobile also argues that small cell technology is "still[] evolving," but that is true of all mobile wireless technology (including macrocell technology), and does not change the fact that wireless providers today are making ever greater use of small cell technologies to effectively fill coverage and capacity gaps both inside and outside of buildings.[35] T-Mobile also asserts, with no supporting evidence, that "a patchwork of cross-jurisdictional regulatory requirements often makes placing a DAS as, or even more, challenging than siting a tower."[36] As the Commission well knows, all providers face regulatory challenges in deploying any type of cell site, but that does not mean that providers using high-frequency spectrum would not or do not surmount these challenges to deploy cost-effective small cell solutions to address in-building penetration issues (including in-building solutions that typically do not trigger the regulatory challenges associated with outdoor solutions), and it certainly provides no basis for completely ignoring small cell solutions.

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[32] Informa Telecoms & Media, *Small Cell Market Status* (Feb. 2013), at 3, *available at* http://www.smallcellforum.org/smallcellforum_resources/pdfsend01.php?file=050-SCF_2013Q1-market-status%20report.pdf.

[33] Description of Transaction, Public Interest Showing, and Related Demonstrations, *Applications of T-Mobile License LLC and Metro PCS Communications, Inc. for Consent to Assign Licenses*, WT Docket No. 12-301, at 30 (Oct. 18, 2012) ("Retention of the [MetroPCS] DAS sites significantly improves the ability of Newco to meet the capacity needs of its customers as well as to improve in-building coverage. . . . The incorporation of these sites and DAS will thus provide substantial benefits to consumers that would not be possible without the creation of Newco. As a result, Newco will enjoy better network density in key urban areas due to all the network synergies that will be realized as a result of the proposed transaction.").

[34] McDiarmid Decl. ¶ 19 (emphasis added).

[35] *Id.* ¶ 21.

[36] *Id.* ¶ 19.

T-Mobile claims that one of the main reasons cited by its customers for leaving T-Mobile is that T-Mobile lacked coverage in their home or office, and T-Mobile blames these churn rates on T-Mobile's lack of low-band spectrum. But T-Mobile provides no evidence that the coverage-related issues cited by its former customers were caused by a lack of low-frequency spectrum. Moreover, marketplace evidence indicates that T-Mobile's churn was not caused by its lack of low-frequency spectrum. **[BEGIN HIGHLY CONFIDENTIAL]** [redacted] **[END HIGHLY CONFIDENTIAL]** The reality is that all carriers, including those with low-band spectrum, face challenges with respect to indoor coverage. In all events, to the extent T-Mobile's network-related churn did materially exceed that of its peers, that would likely reflect (as explained further below) T-Mobile's historic underinvestment in its network, not the characteristics of its spectrum holdings.

Finally, T-Mobile attempts to establish that its network costs are greater than Verizon's by comparing T-Mobile's 2013 per-customer Capital Expenditures ("CAPEX") to Verizon's per-customer 2013 CAPEX. According to T-Mobile, "[p]ublicly available financial data shows that T-Mobile spends $90.79 per customer year on CAPEX – nearly as much per customer as Verizon, which spends $91.68 per customer per year – even though T-Mobile's coverage footprint remains much smaller."[37] This comparison is invalid for at least two reasons. First, as T-Mobile concedes, "[s]pectrum licenses and related expenditures are not included in CAPEX."[38] As a result, T-Mobile's CAPEX comparisons provide no useful information about the relative total costs incurred by T-Mobile and Verizon. Second, comparisons of one year's per-subscriber CAPEX figures are meaningless because such comparisons do not account for the fact that carriers may significantly increase or decrease CAPEX in any given year. This problem is especially relevant here. While Verizon has been consistently making large investments in its network for the past several years, T-Mobile has neglected its network until very recently. For example, whereas Verizon has been steadily upgrading to LTE since 2010, T-Mobile only began launching LTE in 2013. As a result, to the extent that T-Mobile's 2013 CAPEX figures are considered high compared to Verizon's, that is not because T-Mobile is deploying high-frequency spectrum, but because T-Mobile is trying to catch up after historic neglect of its

[37] *Id.* ¶ 29.

[38] *Id.*

network.[39] Third, T-Mobile's "per customer" figures obscure the fact that Verizon's overall capital expenditures are more than double those of T-Mobile's capital expenditures, which also explains why Verizon has been able to achieve a larger footprint.

Public Interest Harms. On this record, Sprint and T-Mobile have failed to establish any record basis for the Commission to adopt rules limiting the ability of any provider to acquire additional low-frequency spectrum. Accordingly, the Commission should reject proposals by Sprint and T-Mobile to modify the spectrum screen or otherwise adopt spectrum aggregation or auction policies that would separately examine how much low-frequency spectrum a provider holds. In particular, the Commission should reject Sprint and T-Mobile's argument that the Commission should establish rules for the upcoming 600 MHz auction that would restrict the ability of AT&T and Verizon to participate fully. As AT&T has previously demonstrated, a "set aside" of any type will only undermine the Commission's ability to meet its revenue goals.[40] In that regard, T-Mobile just submitted a White Paper by Professor Peter Cramton that expressly recognizes that denying auction participants the ability to bid effectively for less two blocks of spectrum "may result in revenue loss" in the 600 MHz auction.[41]

Sincerely,

/s/ *David L. Lawson*
David L. Lawson

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[39] For example, T-Mobile's capital expenditures in 2013 were about 50 percent higher than in 2010, whereas Verizon's 2013 capital expenditures increased by only 12 percent since 2010 (reflecting Verizon's steady high capital investments over time in its network). *See* Quarterly Results, T-Mobile Investor Relations, http://investor.t-mobile.com/QuarterlyResults.aspx?iid=4091145 (last visited May 2, 2014); *see also* Verizon, SEC Filings, http://www.verizon.com/investor/secfiling.htm (last visited May 2, 2014).

[40] Michael L. Katz et al., *Comment on the Submission of the U.S. Dep't of Justice Regarding Auction Participation Restrictions* (June 13, 2013), at ¶ 21, attached to Letter from David L. Lawson, Counsel for AT&T, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268, WT Docket No. 12-269 (June 13, 2013).

[41] Peter Cramton, *Lessons from the Canadian 700 MHz Auction*, at 2 (Apr. 3, 2014), attached to Letter from Trey Hanbury, Counsel to T-Mobile USA, Inc., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268 & WT Docket No. 12-269 (Apr. 3, 2014).

ATTACHMENT A

Reed-Tripathi Response

The Value of Spectrum: A Further Response to Sprint

Jeffrey H. Reed and Nishith D. Tripathi[1]

Reed Engineering

Abstract

This paper responds to a recent submission by Sprint (the Sprint Response Paper or the "SR Paper") that supplements a previous submission by Kostas Liopiros on behalf of Sprint (the "KL Paper"). The KL Paper proposed a weighting scheme for the FCC's spectrum screen, with much higher weights for low-frequency spectrum than for high-frequency spectrum. These weights were derived from asserted relative "values" of different spectrum frequencies based on estimates of the relative number of cell sites needed to deploy low- and high-frequency spectrum. In an earlier paper, we demonstrated that this weighting scheme is invalid because: (1) the relative value of spectrum depends on numerous other factors in addition to the relative number of cell sites and the KL Paper's failure to account for these other factors significantly inflates the relative value of high- and low-frequency spectrum; (2) the well-accepted industry models and empirical evidence confirm that the KL Paper inflates relative differences in the number of cell sites needed for low- and high-frequency deployments; and (3) modern deployments are not coverage-driven green-field deployments (as the KL Paper assumes) but are overlay deployments with mixed low- and high-frequency spectrum, with the most important considerations being capacity and simplicity of radio network design. The SR Paper inherits the flaws in the KL Paper, and adds new ones. First, the analysis in the SR Paper uses the same relative number of cell sites for low- and high-frequency deployments developed in the KL Paper. As a result, the findings in the SR Paper are based on the same invalid cell site counts developed in the KL Paper. Second, the SR Paper's analysis of costs significantly understates one key cost – the cost of the underlying spectrum licenses – which, as we explain in this paper, overstates any overall deployment cost differences. Third, the results of the SR Paper confirm that the proposed weights in the KL Paper are invalid. As just one example, the KL Paper determined that in suburban areas, a 2.5 GHz deployment would require 7 times more cell sites (and 7 times more cost) than a Lower 700 MHz deployment. The SR Paper, on the other hand, contends that, after accounting for spectrum costs (even understated spectrum costs), a 2.5 GHz green-field coverage deployment would cost less than twice as much as a Lower 700 MHz deployment. And in the real world, of course, one can expect relative spectrum prices to reflect all differences that materially impact spectrum value.

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[1] Professor Jeffrey H. Reed is the Director of Wireless at Virginia Polytechnic Institute and State University ("Virginia Tech") and the Willis G. Worcester Professor of Electrical and Computer Engineering at Virginia Tech. Professor Nishith Tripathi is a principal consultant at Award Solutions, a provider of technical consulting and specialized technical training for wireless communications. Dr. Tripathi is also an Adjunct Assistant Professor at Virginia Tech. Professor Reed and Dr. Tripathi previously submitted their vitas in a paper attached to AT&T's Jan. 7, 2013 Reply Comments in FCC WT Docket No. 12-269.

1. EXECUTIVE SUMMARY

AT&T has asked us to review a recent submission by Sprint (the "SR Paper"),[2] which is a response to our March 14, 2014 paper, in which we demonstrated that the spectrum weighting scheme set forth in Sprint's February 11, 2014 submission (the "Kostas Liopiros paper" or "KL Paper")[3] is unsupported by engineering principles and empirical evidence. As we explain below, the SR Paper is flawed in a number of respects.

First, the SR Paper retains as its foundation the incorrect results from the KL Paper. As we explained in our previous paper, the KL paper greatly overstates the differences in the number of cell sites needed for low- and high-frequency deployments. The SR Paper uses those invalid results to estimate differences in deployment costs for low- and high-frequency deployments, *i.e.,* the SR Paper considers capital costs and operating costs but still uses the number of cell sites derived in the KL Paper. By using the invalid relative cell site counts from the KL Paper, the SR Paper greatly inflates the relative cost differences between low- and high-frequency deployments.

Second, the SR Paper understates the extent to which spectrum license costs will offset any differences in deployment costs due to differences in the number of cell sites needed for low- and high-frequency deployments. As the economists have explained, to the extent that it costs less to deploy low-frequency spectrum, providers will be willing to pay more for that spectrum, thus driving up the cost of low-frequency spectrum. As a result, the cost of spectrum licenses can be expected to largely offset any lower deployment costs. This is an issue mainly in rural areas, where it may be possible to deploy lower-frequency spectrum at a lower cost. One obvious mistake in the SR Paper is that it erroneously assumes that it is generally possible to purchase rural-only spectrum licenses at a large discount, when in fact spectrum licenses are typically available only for larger geographic areas that also include non-rural areas, resulting in much higher spectrum license costs than the costs assumed in the SR Paper. Similarly, the SR Paper utilizes an average suburban low-frequency spectrum price that is inconsistent with its suburban definition, which encompasses extremely dense urban areas characterized by much higher spectrum prices. By understating the cost of low-frequency spectrum in this way, the SR Paper understates the extent to which spectrum licenses costs negate any deployment-related cost benefits of low-frequency spectrum.

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[2] Lawrence R. Krevor (Sprint, Legal and Government Affairs), Richard B. Engelman (Sprint, Legal and Government Affairs), Rafi Martina (Sprint, Legal and Government Affairs), and Dr. Liopiros (Sun Fire Group), *The Imperative for a Weighted Spectrum Screen: Low-, Mid-, and High-Band Frequencies Are Not Freely Substitutable Market Inputs*, WT Docket No. 12-269 (April 4, 2014) ("SR Paper"), attached to Letter from Lawrence R. Krevor (Sprint) to Marlene H. Dortch (FCC), *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269 (April 4, 2014).

[3] The KL Paper is attached to the Letter and Report from Lawrence R. Krevor, Vice President for Legal and Government Affairs, Sprint, to Marlene H. Dortch, Secretary, Federal Communications Commission (Feb. 11, 2014).

Third, we note that the SR Paper confirms that the spectrum weights proposed in the KL Paper are invalid. For urban areas, the KL Paper's incorrect analysis found that a provider using 2.5 GHz spectrum would need to deploy 2.6 times more cell sites than a provider using 700 MHz spectrum, and the KL Paper suggests that 700 MHz should thus be given 2.6 times more weight in the FCC's spectrum screen than 2.5 GHz spectrum. The SR Paper, however, makes no attempt to defend this analysis or to estimate relative urban deployments costs that account for spectrum costs. For suburban areas, the KL Paper found that a 2.5 GHz deployment would require 7 times more cell sites than a 700 MHz deployment, and thus recommended that 700 MHz spectrum be weighted 7 times more than 2.5 GHz spectrum in rural areas. The SR Paper, by contrast, after overlaying certain cost metrics onto the results in the KL Paper, predicts that the a high-frequency deployment would cost only about 1.9 times more than the low-frequency deployment. Moreover, the claimed difference would disappear altogether if the errors in the KL Paper were corrected so that the assumed 7 times difference in the number of cell sites were reduced to more reasonable values (we identified more reasonable values in our prior paper).

The remainder of this paper is organized as follows.

In Section 2, we respond to the SR Paper's reasons for ignoring the many conceptual flaws in the analysis of the number of cell sites needed to deploy low- and high-frequency spectrum. The SR Paper continues to premise its analysis on the incorrect assumption that the only factor that determines the relative value/utility of spectrum is its relative propagation characteristics, as set forth in the KL Paper. In fact, propagation is just one of many factors that determine the value of spectrum in a particular deployment, including, for example, compatibility and contiguity with the operator's other spectrum holdings, the ability to implement capacity-enhancing technologies (*e.g.,* Multiple-Input Multiple-Output ("MIMO")), and international harmonization of spectrum bands. Furthermore, as wireless demand is rapidly increasing and network investment is typically driven by capacity needs (as opposed to coverage in green-field deployments in areas with low subscriber density), relative propagation advantages are much less important. We show that the SR Paper's reasons for continuing to ignore these factors and focusing instead only on the propagation characteristics of spectrum in hypothetical green field, coverage-only deployments are not supported by fundamental engineering principles and real-world considerations.

In this same Section 2, we address the SR Paper's two new arguments that there are other factors that make low-frequency spectrum more valuable than high-frequency spectrum. First, the SR Paper argues that low-frequency spectrum is valuable because low-frequency providers do not have to deploy small cells until the demand for capacity develops, whereas high-frequency spectrum must be deployed with small cells from the start. But this argument ignores that the demand for capacity already exists in most urban and suburban areas, so that this supposed "benefit" of low-frequency spectrum is of little practical relevance today. In capacity-driven scenarios, both a low-frequency network and a high-frequency network need to use cells that are smaller than the maximum size allowed by the link budget. Similarly, indoor coverage issues will necessitate smaller cells for both low-frequency and high-frequency networks (not just for high-frequency networks only). The SR Paper has not provided any evidence to the contrary. Second, the SR Paper argues that even if high-frequency spectrum is adequate – and even superior to – low-frequency spectrum in a given area, network operators still require a minimal amount of low-frequency spectrum to provide a "coverage layer." But in urban and suburban areas where capacity is high and cell size must therefore be very small, there will be few if any areas (including inside buildings) that could not adequately be covered by a high-frequency deployment; and the SR Paper has made no case that a low-frequency "coverage layer" would provide any significant additional coverage. Certainly, we have seen no evidence that any provider would be foreclosed from competing without such a coverage layer. To the contrary, we understand that T-Mobile has been adding record numbers of new customers using only high-frequency deployments. In all events, both T-Mobile and Sprint already have a "coverage layer" of at least 5x5 MHz, and in some areas larger blocks, of low-frequency spectrum.

In Section 3, we address the SR Paper's argument that low-frequency spectrum is inherently more competitively valuable in urban areas due to more favorable building penetration characteristics. We show that the SR Paper has not addressed any of the problems with the KL Paper's prior analyses that clearly overstate building penetration differences, erroneously focus on absolute in-building signal levels rather than Signal-to-Interference plus Noise Ratios ("SINRs"), fail to account for the offsetting frequency-specific characteristics that give high-frequency spectrum in-building advantages, and fail to account for widespread and increasing use of small-cell and other technologies used to address in-building performance in modern networks. As just one example, the SR Paper continues to defend an assumption that low-frequency spectrum is uniformly and significantly better at penetrating buildings, even though the very studies cited by the KL Paper show that this assumption is invalid and even though the SR Paper now concedes that, according to these analyses, building penetration (at best) only "can *potentially* increase with decreasing frequency," depending on the materials and design of the buildings.[4]

In Section 4, we explain that the SR Paper's overlay of various costs on top of the flawed KL Paper analysis necessarily leads to flawed results. Indeed, the SR Paper continues to ignore (i) the many other factors that affect spectrum value and utility and (ii) the flaws in its calculations of the relative number of cell sites deployed in low- and high-frequency networks. In addition, the SR Paper's attempt to account for the cost of spectrum licenses is flawed because the SR Paper uses severely discounted spectrum license costs.

2. THE MULTIPLE IMPORTANT FACTORS THAT AFFECT RELATIVE SPECTRUM VALUES (AND UTILITY) THAT SPRINT CONTINUES TO IGNORE

The SR Paper, by relying on the relative number of cell sites for low- and high-frequency deployments as determined by the KL Paper, retains all of the flaws we previously identified in the KL Paper. The only thing the SR Paper adds is an attempt to account for certain additional

[4] SR Paper at 23.

cost metrics (*e.g.*, spectrum license costs, operating costs and capital expenditures). But the SR Paper still fails to account for the many other factors that have a significant impact on the relative value and utility of low- and high-frequency spectrum that are not reflected in the KL Paper. In our prior paper, we identified a number of factors other than propagation that also have a significant impact on spectrum values and utility, and the reasons given in the SR Paper for continuing to ignore them are invalid.

2.1 Compatibility With Existing Spectrum Holdings

In our prior paper, we demonstrated that an important factor in determining the value of spectrum to any particular service provider is the extent to which the spectrum is compatible with the service provider's existing spectrum holdings. For example, a holder of AWS spectrum may prefer more AWS spectrum to a low-frequency spectrum band in which the provider does not currently operate, because the additional AWS spectrum, unlike the low-frequency spectrum, would be compatible with the provider's existing facilities and the devices already being used by its customers. The SR Paper admits that "[n]o one disagrees" with this fundamental engineering fact. Nonetheless, the SR Paper attempts to justify ignoring this factor by arguing that the benefits of having contiguous spectrum are offset by the cost savings of using low-frequency spectrum rather than high-frequency spectrum in new deployments. The SR Paper provides no evidence that the benefits of contiguous spectrum will be fully offset by these asserted cost savings, and it is clear that in many instances there are no offsetting cost savings for low-frequency spectrum, such as in urban and suburban areas where low- and high-frequency deployments require similar numbers of cell sites. Even to the extent that the benefits of low-frequency spectrum may be partially offset, that does not mean that the benefits of having contiguous spectrum are *irrelevant* and should be ignored, as the KL Paper and the SR Paper do. The SR Paper's other argument is that future devices may support more frequency bands, so that in the future some devices might be compatible with new frequency bands deployed in a network. Even in such a future scenario, adding a new frequency band to a device would entail costs, but in any event that also is not a reason to ignore the benefits of having contiguous spectrum.

2.2 Contiguous Blocks

Another factor that significantly affects the value of spectrum is the extent to which it is available in large spectrum blocks. Providers typically place a significant premium on spectrum that is available in large contiguous blocks, because mobile broadband services can typically make much more efficient use of large contiguous blocks of spectrum. The fact that higher-frequency spectrum is more typically available in larger contiguous blocks than lower-frequency spectrum increases the "utility" of high-frequency spectrum relative to low-frequency spectrum. The SR Paper admits that "[o]f course, large contiguous blocks confer advantages" and that "there are more aggregation opportunities at high frequencies."[5] Nonetheless, the SR Paper ignores this factor on the grounds that "low-band spectrum" has "opportunities" for

[5] SR Paper at 20.

"10+10 megahertz blocks."[6] But that is not a legitimate reason for ignoring the significant value of being able to obtain much larger 20x20 MHz blocks (and even 40x40 MHz blocks) in high-frequency spectrum bands. Indeed, large contiguous bandwidth and carrier aggregation at 2.5 GHz are some of the key reasons that Sprint claims that its Sprint Spark service can reach speeds of up to 2 Gbps in a cell (sector).[7] The laws of physics would prevent a low-frequency deployment from achieving the amount of contiguous bandwidth and the degree of carrier aggregation that would be easily achievable in higher frequency bands. In practice, AT&T and Verizon have been able to use only 10-MHz-wide channels at 700 MHz, while Sprint could easily use 20 MHz channels at 2.5 GHz. Sprint could further easily combine multiple 20 MHz channels at 2.5 GHz using carrier aggregation (*e.g.*, as part of the Sprint Spark program).

2.3 Inter-Cell Interference

For urban and suburban deployments, where cell sizes must be small, low-frequency deployments can be subject to significant inter-cell interference. To mitigate inter-cell interference, providers use various techniques, including, among others, antenna down-tilting, reducing antenna heights, and antenna re-orientation. We pointed out that the need for these mitigation techniques has two important effects that the KL Paper ignored. First, these techniques complicate radio frequency ("RF") planning, design, and optimization, which can adversely affect the value of low-frequency spectrum relative to high-frequency spectrum in areas where providers require smaller cells to address soaring capacity demands. Second, these techniques reduce the ability of low-frequency spectrum to penetrate buildings. For example, antenna down-tilting can significantly reduce signal levels in upper floors of multi-story buildings.

The SR Paper agrees with us that low-frequency spectrum holders "routinely manage interference through sound engineering practices," and that these practices include "chang[ing] antenna tilts, powers, and orientations, among other variables."[8] Still, the SR Paper ignores this factor in its analyses on two grounds. The SR Paper argues that low-frequency spectrum provides the "option" of covering larger geographic areas in urban and suburban deployments. This argument, however, is almost entirely theoretical. The demand for capacity in most of these areas has already resulted in smaller cell sizes, such that providers with low-frequency spectrum have little or no opportunity to take advantage of the theoretical larger cell sizes they can support. Thus, the additional flexibility touted by the SR Paper is of little practical significance in urban and suburban areas. Sprint/Clearwire has contradicted the KL Paper in this regard, stating that high-frequency spectrum is superior to low-frequency spectrum in

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[6] *Id.*

[7] *See, e.g.,* Sprint Press Release, Sprint Spark Currently Delivers 50-60 Megabit Per Second Peak Speeds (October 30, 2013), *available at* http://newsroom.sprint.com/news-releases/sprint-demonstrates-1-gigabit-over-the-air-speed-at-silicon-valley-lab.htm (last visited May 2, 2014) ("Sprint Spark Release").

[8] SR Paper at 19.

areas where demand for capacity is high, as is the case in urban and suburban areas.[9] In any event, the SR Paper provides no evidence that this theoretical increase in flexibility offsets the costs of having to deal with inter-cell interference when it arises.

The SR Paper also argues that even though inter-cell interference mitigation requirements may cause reductions in low-frequency signal levels, such requirements would not necessarily result in significant decreases in quality of service ("QoS") in an LTE system, because "LTE . . . is designed to work in an interference-limited environment."[10] But this argument cuts two ways. The SR Paper cannot argue that lower signal levels for high-frequency spectrum reduces penetration into buildings while simultaneously arguing that inter-cell interference mitigation techniques for low-frequency spectrum, which have similar effects, are irrelevant. We agree with the SR Paper that LTE can operate well in an interference-limited environment. However, as discussed in our original paper, inter-cell interference mitigation techniques for low-frequency spectrum can prevent RF engineers from optimizing SINRs beyond a certain level, restricting the achievable throughput in LTE environments. Hence, the SR Paper's position that the limits of inter-cell interference mitigation techniques can be ignored for low-frequency spectrum is not tenable.[11]

The SR Paper also claims, somewhat rhetorically, that if the need for mitigation techniques affects the value of spectrum, "AT&T should be able to point to an urban area where low-band spectrum has sold at a discount to high-band spectrum." We are not arguing that low-frequency spectrum will necessarily cost less as a result of inter-cell interference alone. Our point is that inter-cell interference is an important factor to consider when measuring the overall relative value of high- and low-frequency spectrum and hence should not be ignored.

Lastly, contrary to the assertions in the SR Paper, we did not assume in our original paper that "the [inter-cell interference] adjustments will always reduce the signal power levels so as to negate the benefits of low-band spectrum." Our point is merely that the techniques used to mitigate inter-cell interference for low-frequency spectrum will necessarily reduce signal levels for low-frequency deployments, and that this factor should therefore be taken into account when analyzing relative signal levels and SINRs for low- and high-frequency deployments. The

[9] *See, e.g.,* Phil Goldstein, Former Clearwire CEO Prusch: Sprint will have advantage with 2.5 GHz spectrum, FierceWireless (Jan. 14, 2014), http://www.fiercewireless.com/story/former-clearwire-ceo-prusch-sprint-will-have-advantage-25-ghz-spectrum/2014-01-14.

[10] SR Paper at 19.

[11] In addition, just like engineering limits (*e.g.*, antenna height) are likely to be reached more frequently while increasing the coverage of a high-band deployment (as the SR Paper mentions), engineering limits (*e.g.*, degree of down-tilting) are likely to be reached more frequently while attempting to reduce coverage to minimize interference in the urban environment of a low-band deployment. Of course, LTE will still work but with relatively lower throughput than the throughput that could have been achieved in the absence of such limits. The RF engineers involved in detailed site-specific RF optimization experience such engineering limits for both low-band and high-band deployments.

KL Paper and the SR Paper fail to do this and the results of their analysis therefore overstate the potential differences in signal levels and SINRs for low- and high-frequency deployments.

2.4 Advanced LTE Technologies

In our initial paper, we made the uncontroversial point (at least among wireless engineers) that high-frequency spectrum is more capable of taking advantage of advanced LTE technologies, such as MIMO technologies. The spatial multiplexing of MIMO enhances throughput by taking advantage of decorrelated parallel signals being captured by multiple antennas. The benefits of MIMO increase with the number of antennas. For example, a 2x2 MIMO configuration (meaning two antennas) provides maximum theoretical throughput of 150 Mbps, whereas a 4x4 MIMO configuration provides maximum theoretical throughput of 300 Mbps for Release 8 LTE.[12]

In light of these facts, we pointed out that one very significant benefit of higher frequency spectrum is that it requires much smaller antennas to transmit and receive signals, which allows more antennas to be placed at the base station and/or within the device, thus supporting a higher order of MIMO and greater throughput for higher frequency deployments compared to lower frequency deployments.[13] The ability to take advantage of higher-order MIMO configurations thus adds a significant value and utility to high-frequency spectrum relative to low-frequency spectrum. Even when more antennas are not used for the mobile device, enhanced downlink performance of beamformed-MIMO would still be achieved for the higher frequency spectrum compared to low-frequency spectrum due to the use of more antennas at the base station. In the uplink, receive beamforming and higher-order receive diversity would improve throughput and reliability due to the availability of more receive antennas at the base station.

The SR Paper's response is to assert that we "suggest that MIMO offers little or no benefit at lower frequencies" and that in fact a 2x2 MIMO configuration has been shown to provide comparable benefits for both low- and high-frequency deployments. This entirely misses our point and is not responsive. We did not attempt to show that MIMO offers little or no benefit for lower frequencies. Rather, as noted above, we showed that MIMO offers much *greater* benefits for higher frequencies than it does for lower frequencies. For example, whereas 700 MHz spectrum typically uses two antennas at the base station, higher frequency spectrum, like

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[12] For example, if a manufacturer puts four antennas in a handset and tries to use (4x4) MIMO, the signals would be much more correlated at 700 MHz than at 2500 MHz, because the wavelength is much smaller at 2500 MHz compared to 700 MHz. Higher correlation among the signals would translate into smaller MIMO gain at 700 MHz compared to 2500 MHz.

[13] These benefits are well documented. *See, e.g.,* WiMAX Forum, *A Comparative Analysis of Spectrum Alternatives for WIMAX Networks with Deployment Scenarios Based on the U.S. 700 MHz Band* (June 2008), at 17, *available at* http://resources.wimaxforum.org/sites/wimaxforum.org/files/document_library/comparative_analysis_of_spectrum_alternatives_for_wimax_networks_with_scenarios_based_on_the_us_700_mhz_band.pdf.

2.5 GHz spectrum, can support four (or even eight, as announced by Sprint's Spark program) antennas at the base station, enabling implementation of enhanced beamforming and facilitating 4x4 (or even 8x8) MIMO configurations.[14] Such enhanced beamforming and MIMO provides significantly enhanced throughput and reliability, which will necessarily increase the value of high-frequency spectrum relative to low-frequency spectrum.[15]

2.5 Duplexer Issues

In our prior paper, we pointed out the well-established engineering fact that a significantly larger range of spectrum can be covered using a single duplexer for high-frequency spectrum than can be covered for low-frequency spectrum. The typical rule of thumb used in the wireless industry is that the maximum "passband" for a duplexer is equal to about 4 percent of the center frequency of the spectrum at issue. As a result, more duplexers are typically needed when using a broad range of low-frequency bands than high-frequency bands. Each duplexer increases costs, creates insertion loss, and increases power consumption. Thus, purely as a matter of wireless engineering, high-frequency spectrum has an advantage because it permits the use of fewer duplexers.

The SR Paper does not dispute these facts. Instead, the SR Paper asserts that 600 MHz duplexers should be able to support 30 MHz.[16] But that is not responsive to our argument, and it only confirms our point. Indeed, a 2.5 GHz duplexer can cover at least 100 MHz, which allows a higher-frequency operator such as Sprint to use more spectrum with fewer duplexers. This is a distinct benefit of 2.5 GHz spectrum. The SR Paper's other argument is that some

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[14] *See, e.g.*, Sprint Spark Release ("These 2.5 GHz radios are expected to have capabilities for 8 Transmitters 8 Receivers (8T8R), which will be a first deployment of its kind in North America. These radios will be capable of improved coverage, capacity and speeds when compared to the more traditional 2T2R or 4T4R radios used by our competitors.").

[15] The use of spatial multiplexing in MIMO systems is one of the key contributors to enhanced performance of 4G systems compared to 3G systems. We have clearly described in our earlier paper several factors that enable a higher band network to achieve better performance than a lower band network when multiple antenna technologies such as spatial multiplexing and beamforming are exploited. Such performance enhancement originates from the following basic mechanisms: (i) better separation of signals for spatial multiplexing at a higher band for a given amount of fixed space, (ii) more signal energy achievable due to the existence of more antenna elements (with the same number of antennas for both low and high bands) at a higher band within a given antenna radome, and (iii) more signal energy achievable by beamforming due to the existence of more antennas at a higher band (e.g., 4 or 8 antennas at a high band and 2 antennas at a low band) within a practical antenna radome. For the handset, both measurements and theory have shown that antenna spacing on the order of 0.2 λ or greater is needed to provide diversity. This is due to mutual coupling between the antennas. Since the wavelength is shorter for high frequencies than lower frequencies, more antennas can be placed on the higher-frequency device than the lower-frequency device. *See* Tokio Taga, "Characteristics of Space-Diversity Branch Using Parallel Dipole Antennas in Mobile Radio Communications," 76(9) Electronics and Communications in Japan (Part I: Communications) 55 (1993).

[16] *See* SR Paper at 19-20.

manufacturers are making devices with multiple low-frequency duplexers for use by all providers, even if a provider is not using the duplexer. But even in those cases, if the provider is not using a duplexer – say because the provider is using mainly high-frequency spectrum – the mobile device of the provider will not experience the insertion loss or power consumption harm from the extra duplexers that are not being used. Low frequency deployments that must use multiple duplexers will experience those harms.

2.6 The Impact Of Using Both High- And Low-Frequency Spectrum, International Harmonization, And Regulatory Requirements

The SR Paper ignores three other factors that can significantly affect the relative value or utility of spectrum.

First, even if spectrum value were determined solely by propagation characteristics, as the KL Paper and the SR Paper erroneously assume, these papers still greatly exaggerate the difference in the number of cell sites that network operators would use in any real-world deployment. The SR Paper ignores that U.S. network operators today usually have a *mix* of low- and high-frequency spectrum. From a wireless engineering standpoint, the most efficient way to deploy multiple frequency bands of spectrum in a single network is to build a cell site grid that facilitates a near one-to-one overlap of coverage for all spectrum frequency bands (to the extent possible). In other words, a network operator that deploys both 700 MHz and PCS (1900 MHz) bands will typically deploy a cell grid to ensure full (or nearly full) coverage using the PCS spectrum, even if fewer cell sites could have been used for a 700 MHz-only deployment in coverage-driven scenarios. As we demonstrated in our prior paper, network operators typically engineer their networks in this way because it greatly simplifies network engineering (thus reducing costs), and because it provides greater network performance.

Second, the SR Paper fails to address the fact that because high-frequency spectrum is used internationally (*e.g.,* AWS and 2.5 GHz), it can have significant advantages relative to low-frequency spectrum, which is used only in the U.S. (*e.g.,* 700 MHz). Frequencies that are used internationally can benefit from lower equipment costs associated with economies of scale, faster-paced development and implementation of new technologies and corresponding standards, and more efficient international roaming solutions.

Third, the SR Paper fails to address the fact that regulatory requirements can have a significant impact on a network operator's valuation of spectrum. For example, as we understand the FCC's build-out requirements, 700 MHz A- and B-Block licensees are required to build out a network that covers 35 percent of the *geographic area* where the spectrum licenses are held within four years, and 70 percent of the geographic area by the end of the lease term.[17] By contrast, the FCC's rules for some high-frequency spectrum bands require only that the network operator offer "substantial service" by the end of the licensed term, which can be 10

[17] *See* 47 C.F.R. §27.14.

or more years.[18] These differences can result in higher deployment costs for low-frequency spectrum license holders than for high-frequency spectrum license holders.

2.7 Sprint's Arguments That We Have Ignored Factors That Make Low-Frequency Spectrum More Desirable

The SR Paper argues that we did not address two additional factors in our prior paper that could increase the relative value or utility of low-frequency spectrum vis-à-vis high-frequency spectrum. Even if that were true, the existence of other factors that cut one way or the other does not justify the KL Paper's and the SR Paper's decision to ignore virtually every factor that would reduce the difference in relative value and utility of low- and high-frequency spectrum. And, in all events, the two factors that the SR Paper cites are not likely to have a significant impact on relative spectrum value or utility.

First, the SR Paper argues that low-frequency spectrum is more valuable in urban areas because providers can use such spectrum solely for coverage and then add cell sites to meet capacity only as demand develops. We agree that this could theoretically be a benefit of low-frequency spectrum if such urban areas were really coverage-driven (as opposed to capacity-driven). However, the demand for capacity in urban areas today is such that demand usually already exceeds the capacity that can be supplied using coverage-only deployments. As a result, in typical urban deployments, smaller cells with sizes reflective of the traffic demand are already required. Thus, this "benefit" of low-frequency spectrum is largely theoretical and is rarely realizable in real-world urban deployments.

Second, the SR Paper argues that it is valuable to have low-frequency spectrum to use as a "coverage layer" to fill in the gaps at indoor or obstructed locations. But both low- and high-frequency commercial networks are designed to provide a certain level of cell-edge reliability, *e.g.,* 90 percent cell-edge reliability.[19] In a capacity-driven deployment, the demand for capacity (and not propagation-related path loss) dictates how many cell sites are needed, so low- and high-frequency deployments would require roughly the same number of cell sites. Because both low- and high-frequency networks are typically designed for the same cell-edge reliability, they have the same coverage. In a capacity-driven green-field coverage deployment or an overlay network, there is no technical reason for a low-frequency network to provide superior performance for these reasons: (i) SINRs and not absolute signal levels dictate the achieved performance and SINR levels would be similar for low-frequency and high-frequency networks as explained in our original paper; and (ii) as long as the received signal is above the receive sensitivity, the absolute signal levels (which would be weaker for high-frequency and relatively stronger for low-frequency due to frequency-based path loss differences) do not

[18] *See id*.

[19] Such reliability is typically reflected by the fading margin used in the link budget, which dictates cell size for coverage-driven deployment and puts an upper limit on the cell size in case of capacity-driven deployment.

matter. In addition, as we explained in our previous paper, to the extent that there are specific coverage gaps, they can typically be efficiently addressed using small cell solutions.

In any event, both T-Mobile and Sprint already have low-frequency spectrum they can use for the type of coverage layer they claim will be beneficial. T-Mobile recently purchased 700 MHz A-Block spectrum from Verizon, covering 70 percent of T-Mobile's customer base. T-Mobile has made clear that a 5x5 block of low-frequency spectrum is all it would need to "dramatically" improve its coverage, and the 700 MHz spectrum it is obtaining from Verizon is a 6x6 block of spectrum. Similarly, Sprint also has low-frequency 800 MHz spectrum, which it is in the process of deploying in its LTE network. Sprint has said that it will have 150 million POPs covered by its LTE spectrum by the end of this year.[20]

3. URBAN AREAS: THE MULTIPLE FACTORS THAT AFFECT DIFFERENCES IN THE NUMBER OF CELL SITES THAT SPRINT'S SUBMISSIONS CONTINUE TO IGNORE

In urban environments, cell size – and hence the number of cell sites needed to meet the desired quality of service – is typically driven by demand for capacity and throughput, not by the link budget-dictated propagation path loss. To meet the demand for capacity and throughput in urban areas, cell sizes must be small, which negates any propagation benefits of low-frequency spectrum related to the required number of base stations, because essentially the same number of cell sites have to be used, regardless of frequency, to meet QoS performance targets.

The KL Paper has acknowledged this fact.[21] It claimed, however, that low-frequency spectrum is more valuable (and has greater utility to network operators) than high-frequency spectrum in urban areas because low-frequency spectrum is better at penetrating buildings, and thus can be deployed with fewer cell sites. Based on this argument and the application of an invalid building penetration loss formula, the KL Paper asserted that a 2.5 GHz deployment would require 2.6 times more cell sites than a Lower 700 MHz deployment and that Lower 700 MHz spectrum should therefore be accorded 2.6 times more weight than 2.5 GHz spectrum in the FCC's spectrum screen.

We demonstrated that the assumptions underlying the KL Paper's analysis of urban deployments were incorrect for a number of reasons, including that it significantly overstates building penetration differences for high- and low-frequency spectrum, erroneously focuses on absolute in-building signal levels rather than SINR, fails to account for the offsetting frequency-specific characteristics that give high-frequency spectrum in-building advantages, and fails to account for widespread and increasing use of small-cell and other technologies used to address in-building performance in modern networks.

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[20] Phil Goldstein, Sprint's Hesse: Spark tri-mode LTE service could eventually provide real-world speeds of 150-180 Mbps, FierceWireless (Dec. 10, 2013), http://www.fiercewireless.com/story/sprints-hesse-spark-tri-mode-lte-service-could-eventually-provide-real-worl/2013-12-10.

[21] KL Paper at 11-13.

The SR Paper does not contain a revised analysis for urban areas. Instead, the SR Paper attempts to argue that our criticisms of the KL Paper's analysis are not valid. As we explain below, the SR Paper's arguments are not supported by wireless engineering principles or real-world evidence. As a preliminary matter, however, we note that the SR Paper's own updated analysis for *suburban* areas confirms that the KL Paper's original *urban* analysis (which the SR Paper has not updated) is invalid. According to the SR Paper's updated suburban analysis (which itself overstates cost differences for low- and high-frequency deployments), a 2.5 GHz deployment costs about 1.9 times more than a Lower 700 MHz deployment, which is less of a difference than the KL paper found even for urban areas (factor of 2.6). Obviously, given that urban deployments typically have cell sizes that are smaller than in suburban areas, the relative cost difference between low- and high-frequency deployments should be smaller, not larger, than the SR Paper's suburban factor of 1.9. Thus, the SR Paper's updated analyses for suburban areas confirm that the KL Paper's original urban analysis – the only urban analysis it has placed in the record – is invalid.

We now turn to the specific responses in the SR Paper purporting to address our criticisms of the urban analysis set forth in the KL Paper.

3.1 Building Penetration

The analysis in the KL Paper was based on the false assumption that high-frequency spectrum is always worse at penetrating buildings than low-frequency spectrum. As we pointed out, even the empirical studies cited by the KL Paper show that the relative ability of high- and low-frequency spectrum to penetrate buildings depends largely on the materials used in the particular building at issue, and that for the types of materials typically used in urban areas, high-frequency signals often penetrate better than low-frequency signals. These studies also showed that for the types of materials typically used for residential buildings (excluding red brick and cinder block), high- and low-frequency signals penetrate equally well. We also cited multiple other studies that show that higher-frequency signals sometimes penetrate buildings better than lower-frequency signals.

The SR Paper's response is that "[c]ontrary to Reed and Tripathi's claims, high-frequency spectrum does not have an advantage in penetrating steel and reinforced concrete construction," *i.e.,* the type of construction typically used in urban areas.[22] But those are not our findings, those are the findings of the report by the Communications Research Centre Canada (CRCC), which is the report that the KL Paper itself relies upon.[23] The CRCC report states:

> [These urban buildings] are often of steel-framed construction, and the corresponding predominant building materials are reinforced concrete, steel, and aluminum; loss through these

[22] SR Paper at 23.

[23] *See* KL Paper n. 26; SR Paper n. 74.

> materials is relatively much higher, and the dominant penetration mode is through slots such as windows and other frame openings, or even through grid openings in steel-reinforced concrete slabs. Losses associated with propagation through slots tend to be strongly frequency-selective, and overall decrease with increasing frequency, as the slot dimensions become larger in terms of the wavelength.[24]

In quantitative terms, as shown in Table 5 of the CRCC Report, some studies have shown that, for the types of materials that dominate urban areas, 2.5 GHz spectrum can experience about 4.3 dB or 37 percent *less* signal penetration loss compared to 700 MHz spectrum.[25]

These findings are consistent with other empirical analyses. A 1992 study measured the average building penetration loss at the ground floor of buildings to be 14.2 dB at 900 MHz, 13.4 dB at 1800 MHz, and 12.8 dB at 2300 MHz.[26] A 1993 study examined building penetration loss in Philadelphia, Pennsylvania, and found that the average building penetration loss was 19.2 dB at 880 MHz and 15.7 dB at 1922 MHz.[27] And an earlier 1987 study in Liverpool, England found building penetration loss to be 16.4 dB at 441 MHz, 11.6 dB at 896.5 MHz, and 7.6 dB at 1400 MHz.[28]

The SR Paper's other response is to speculate that these results may vary depending on the "presence, size and orientation of windows," and that in certain situations, low-frequency

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[24] Communications Research Centre Canada, *Comparison of Radio Propagation Characteristics at 700 and 2,500 MHz Pertaining to Macrocellular Coverage* (April 2011), at 24-25 ("CRCC Report"); *see also id.* at 24 ("several researchers have reported measurements indicating that building penetration loss decreases with increasing frequency"); *id.* ("Apparently conflicting results have been reported in the literature concerning the dependence of building penetration loss on frequency [13–15]. While several researchers have reported measurements indicating that building penetration loss decreases with increasing frequency in the VHF and UHF range [14], results by other researchers suggest the opposite, for example see [13, 16–18], or that there is no significant dependence on frequency at all [11].").

[25] CCRC Report at 25. *See also. e.g.,* Y.L.C. de Jong and D.V. Rogers, *Comparative Evaluation of Macrocellular and In-building Wireless Coverage Performance at 700 and 2500 MHz*, 7th European Conference on Antennas and Propagation (EuCAP 2013), at 3978 (April 8, 2013) ("In both macrocellular and in-building coverage scenarios, the lower free-space propagation loss associated with lower frequencies is counteracted by an increased likelihood of Fresnel zone blockage by terrain obstructions and the building structure, respectively.").

[26] A. F. de Toledo and A. M. D. Turkmani, "Propagation Into And Within Buildings At 900, 1800, And 2300 MHz," IEEE 42nd Vehicular Technology Conference, pp. 633-636 (May 1992).

[27] William J. Tanis II and Glenn J. Pilato, "Building Penetration Characteristics of 880 MHz And 1922 MHz Radio Waves," IEEE 43rd Vehicular Technology Conference, pp. 206-209 (May 1993).

[28] A. M. D. Turkmani, J. D. Parson, and D. G. Lewis, "Radio Propagation Into Buildings at 441, 900, and 1400 MHz," Proceedings of 4th International Conference on Land Mobile Radio (Dec. 1987).

spectrum “can potentially” penetrate buildings more effectively.[29] In other words, the SR Paper (as does the KL Paper) implicitly *agrees* with us that it is not correct to assume that low-frequency spectrum always penetrates buildings better than high-frequency spectrum.

3.2 Other Important Factors Affecting Relative In-Building Coverage For Low- And High-Frequency Spectrum

The SR Paper also either ignores or inadequately addresses other important factors we have identified that further refute the assumption that low-frequency spectrum always provides better in-building coverage with fewer cell sites compared to high-frequency spectrum.

First, as we demonstrated in our prior paper, the KL Paper’s analysis fails to account for the mitigation techniques that must be used for low-frequency deployments to minimize inter-cell interference. As we discussed above, the fact that low-frequency spectrum travels farther than higher-frequency spectrum is a liability in dense cell deployments because it results in relatively higher inter-cell interference that must be mitigated by, for example, antenna down-tilting and antenna height reductions, which in turn reduces low-frequency coverage. The SR Paper concedes this point. It admits that for low-frequency deployments, inter-cell “interference must be managed” and that “operators trade off low-band spectrum’s coverage advantages for capacity.”[30] The techniques such as antenna down-tiling and antenna height reduction can reduce in-building coverage by reducing the power of signals below receive sensitivity levels or by reducing SINR levels. For example, in “vertical” urban areas, like New York or Chicago, antenna down-tilting alone will severely reduce coverage in upper floors of tall buildings. As a result, to reach these upper floors, it is often necessary to add cell sites pointed towards those floors or to deploy other solutions such a Distributed Antenna System (“DAS”) and small cells, thus increasing the number of cell sites (and costs) for low-frequency deployments relative to high-frequency deployments.

Second, as we demonstrated in our prior paper, the KL Paper’s and thus the SR Paper’s analyses fail to account for the fact that high-frequency deployments can typically achieve higher antenna gain (about 2-3 dB higher) than low-frequency deployments, which can significantly or completely offset *any* building penetration benefits of low-frequency spectrum. The SR Paper admits that the smaller size antenna elements needed at higher-frequency deployments do indeed enable higher gains in the horizontal direction. The SR Paper argues, however, that these higher horizontal gains are obtained at the expense of reduced vertical gain. But that is not a reason for ignoring the higher gains and resulting higher building penetration capability of high-frequency deployments in lower floors and in the many urban areas that are not characterized by high-rise buildings.

The SR Paper also argues that the higher horizontal gains achieved by high-frequency spectrum are attained with narrower horizontal beamwidths, and thus an additional antenna may be

[29] SR Paper at 23.

[30] SR Paper at 19.

required to ensure the same coverage. To begin with, the difference in horizontal beamwidths is insignificant (68 degrees and 60 degrees for 700 MHz and 2300 MHz, respectively). Moreover, narrower beamwidths for 4G systems such as LTE are typically *preferred* to wider beamwidths due to the lack of soft handover and the need for minimal overlap among the cells to minimize inter-cell interference. Furthermore, antennas with different characteristics exist, and suitable antennas that help with solving a coverage hole can be utilized. Other RF tuning mechanisms such as changes in antenna azimuth are also available to solve such specific issues. These mechanisms are routinely used by RF planning, design, and optimization tools such as Atoll. And high-frequency deployments are typically deployed with more antennas, and these additional antennas cost a fraction compared to adding a new base station, as the SR Paper implicitly assumes. Finally, the SR Paper argues that these higher antenna gains will not matter when multiple walls must be penetrated. But this argument presupposes that high-frequency signals will always experience more penetration loss than low-frequency signals, which, as explained above, is not a valid assumption.

Third, the SR Paper completely ignores the fact that its analysis incorrectly assumes that in every instance where the building materials would result in more penetration loss for higher-frequency signals, it will result in reduced in-building coverage. In fact, the QoS in mobile wireless networks is typically governed by the SINR, *i.e.,* the *ratio* of power of the desired signal to the power of the undesired signals. Therefore, even in cases where high-frequency signals achieve lower absolute in-building signal levels than low-frequency signals, that fact alone does not determine which network will achieve better in-building QoS, because QoS depends primarily on the relative levels of *undesired* signals in the building. If the materials of a particular building are “more porous” (*i.e.,* permit less penetration loss) to low-frequency signals, then the low-frequency deployment will experience higher levels of both desired and undesired signals. At the same time, the high-frequency network will experience lower levels of both the desired and undesired signals. Because the SINR is the ratio of the power of the desired signal to the power of the undesired signals, the SINR for both deployments could be quite similar.

3.3 Small Cells

The KL Paper’s and hence the SR Paper’s analyses of the relative number of cell sites that would be needed for low- and high-frequency deployments in urban areas implicitly assume that a network operator would always deploy a new macrocell site to address discrete in-building coverage issues. As a result of this assumption, the KL Paper concluded that, in urban areas, a network operator using 2.5 GHz spectrum would have to deploy more than 2.5 times the number of cell sites to achieve equivalent in-building coverage as a 700 MHz operator. That result is simply not credible. In these urban areas, where cell sizes will be small to meet capacity demands, most buildings will be near a cell site and will thus have adequate indoor coverage. The “problem” buildings will be the minority that are near the cell edge (or obstructed). And, as we have explained, the better solution for those buildings will typically be small-cell solutions (*e.g.,* iDAS, Femtocells, and WiFi) designed to cover the relatively small indoor area, which is far more cost effective than deploying a cell site that would cover a much larger geographic area. Moreover, for the reasons described above, indoor coverage – and the need for small cell solutions – is an issue for *both* low- and high-frequency deployments, and manifestly is not a problem specific to any frequency.

The SR Paper's only response is that it has "acknowledge[ed] that '[i]n-building coverage can also be improved through the use of femtocells and picocells that can be installed indoors or in areas immediately adjacent to buildings.'"[31] But acknowledging this fact and actually accounting for it in the analysis of the relative number of cell sites for low- and high-frequency deployments are two different things. The fact is that the analyses of the relative number of cell sites for high- and low-frequency deployments set forth in the KL Paper and hence in the SR Paper completely ignore the need, availability and applicability of small-cell solutions for both high-frequency and low-frequency networks. Rather, the KL Paper's and the SR Paper's analyses assume that in every case where there is an in-building coverage issue, a service provider will deploy one or more macrocell sites to fill the gap, rather than a more efficient small-cell solution.

The SR Paper provides two invalid reasons for ignoring in-building solutions.

First, the SR Paper asserts that the "vast majority of indoor locations will continue to be served by outdoor 'macro' transmitters."[32] But that undermines arguments in the SR Paper; indeed, that is our point. For both high- and low-frequency deployments, most buildings will be adequately served by outdoor macrocell sites, especially in urban and suburban environments with small cell densities where most buildings will be relatively close to a cell site. Thus, for the relatively small number of buildings near the cell edge (or obstructed) where coverage gaps may occur, it will often be far more effective and practical (*e.g.*, lack of availability and suitability of real estate to locate macro base station facilities) to deploy a small cell solution rather than deploying one or more additional cell sites.

Second, the SR Paper argues that small-cell deployments are not cost effective. This argument, of course, is refuted by the wide-spread use of small cells by all providers, including T-Mobile and Sprint, as we documented in our prior paper. Moreover, these arguments are based on an invalid comparison of macrocell costs to small-cell costs. For example, T-Mobile argues that deploying DAS systems is not cost-effective because "to achieve *coverage equivalent to a macrocell*, the average cost is . . . more than that of a macrocell."[33] But we are not suggesting that DAS systems would be deployed to cover an area equivalent to a macrocell. Rather, the issue here is attaining coverage within the discreet number of buildings nearer to the cell edge or that are obstructed that may lack in-building coverage. Supporters of the type of analysis in the SR Paper have also argued that small-cell technology is "still evolving," but that is true of all

[31] SR Paper at 23.

[32] SR Paper at 23-24.

[33] Declaration of Mark McDiarmid, attached to Letter from Trey Hanbury (counsel to T-Mobile) to Marlene H. Dortch (FCC Secretary), GN Docket No. 12-268, WT Docket No. 12-269, ¶ 19 (April 1, 2014) ("McDiarmid Decl.").

mobile wireless technology (including macrocell technology), and does not change the fact that current small-cell technologies can be and are being used to effectively fill coverage and capacity gaps both inside and outside of buildings.

It is also critical to recognize that assertions in the SR Paper and elsewhere regarding the evolving technology and costs of small cell solutions are reasons *not* to base FCC policy on such factors. The one thing that is absolutely clear is that small-cell technology is rapidly improving and costs are plummeting. Thus, even if it were true (in fact, it is not true) that small-cell solutions were not a viable alternative today, the FCC should, of course, base its long term policies – including its policies governing spectrum aggregation – on clear and obvious industry trends, including the fact that small-cell technologies are rapidly improving as costs fall.

4. SUBURBAN AND RURAL ANALYSIS

The analysis in the KL Paper and hence in the SR Paper of the relative costs of low- and high-frequency spectrum for rural and suburban areas – which are then equated to relative "value" or "utility" – also includes numerous flaws that significantly inflate the relative value/utility of low- and high-frequency spectrum, and hence overstate the weights that are proposed for low-frequency spectrum in the FCC's spectrum screen. As we discuss below, the SR Paper has not addressed any of the fundamental engineering flaws in the original analysis in the KL Paper. The only change that the SR Paper appears to have made is to account for items such as capital costs, operating costs, and spectrum license costs. Although we agree that these costs are relevant and should be included in any analysis of the relative value of spectrum, the SR Paper's approach does not accurately capture these costs, resulting in inflated relative value/utility calculations and thus inflated low-frequency weighting proposals.

4.1 The Legacy Problems In Sprint's Suburban And Rural Analyses That Are Not Addressed In Sprint's Revised Analysis

The SR Paper's analyses for suburban and rural areas retain and start with the KL Paper's propagation-based relative cell site analysis. The SR Paper merely overlays costs onto the KL Paper's analysis. Consequently, the SR Paper, like the KL Paper, assumes that in suburban areas, a 2.5 GHz deployment will require 7 times more cell sites than a Lower 700 MHz deployment,[34] and that in rural areas a 2.5 GHz deployment will require about 14 times more cell sites than a Lower 700 MHz deployment.[35] As we demonstrated in our prior paper, these results are based on invalid modeling techniques and assumptions, and the SR Paper provides no legitimate response to our criticisms.

The KL Paper itself conceded that no single mathematical formula can be used to correctly engineer both low- and high-frequency networks. Yet for suburban and rural areas, the KL Paper relies entirely on a single "simplified" path loss model that it contended was consistent

[34] *See* SR Paper at 12.

[35] SR Paper at 10.

with the "Lee model" (which was developed in 1980s for 900 MHz spectrum) to compute the number of cell sites that would be needed for each spectrum frequency band. Because the SR Paper retains and continues to depend on this flawed approach, the new paper attempts to deflect our criticisms of it. None of these responses is correct.

First, we refuted the assumption in the KL Paper that the number of cell sites (*i.e.,* cell density) in suburban areas, as defined by the KL Paper, is driven entirely by path loss, *i.e.,* coverage, considerations. The KL Paper defines suburban areas to be census tracts with population densities lower than 10,000 people/square mile. By that definition, about half of downtown Washington D.C., most of downtown Atlanta, GA, parts of New York City, and many crowded commuting corridors, airports, train stations, and other areas where cell density is clearly capacity-driven are incorrectly defined to be coverage-driven "suburban" areas under the KL Paper's analysis. By incorrectly categorizing a number of capacity-driven areas as coverage-driven areas, the KL Paper greatly overstates the overall relative number of additional cell sites needed for high-frequency deployments.

The reason the SR Paper gives for ignoring this problem with its analysis is that reducing the population cut-off it assumes for suburban areas would not materially change its proposed spectrum weights.[36] But the SR Paper's own new calculations clearly show that reducing the suburban cut-off to 1,000 people per square mile (the threshold used by the U.S. Census Bureau)[37] reduces the difference in the assumed number of cell sites and hence the difference in the proposed spectrum screen weights that are proposed for 2.5 GHz spectrum and 700 MHz spectrum *by about half*.[38]

Second, as we previously demonstrated, even for the subset of "suburban" and "rural" areas where cell density is coverage-driven in a green-field deployment, the KL Paper's (and hence the SR Paper's) use of the simplified propagation model overstates how many additional cell sites are needed for high-frequency deployments relative to low-frequency deployments. The model used by the KL Paper and the SR Paper assumes that the number of cell sites that must be deployed in a coverage-driven deployment is determined solely by the frequency-specific propagation characteristics of desired signals of the spectrum. As a result, the simplified model fails to account for the many other characteristics of spectrum (discussed in Section 2, above) that also significantly affect the relative number of cell sites needed for high- and low-frequency deployments.

In our prior paper, we demonstrated that, to engineer coverage-driven deployments, network operators use complex network planning and design tools that (i) use propagation models specifically calibrated for the relevant frequency and the topology and (ii) reflect differences in antenna gains, spatial separation, antenna patterns, and numerous other frequency-specific

[36] *See* SR Paper at 27 ("any reasonable threshold for urban, suburban, and rural will have little to no effect on the weighting analysis").

[37] *See* Urban Area Criteria for the 2010 Census, 76 Fed. Reg. 53029, 53040 (Aug. 24, 2011).

[38] *See* SR Paper at 28.

factors, as well as geographic characteristics, such as clutter (*e.g.*, buildings, trees, etc.) and terrain detail (*e.g.*, mountains). And network engineers then analyze the results of these tuned models to account for real-world limitations, including the feasible height of the base stations, the feasible locations of the base stations, the need to cover (or not cover) particular areas (*e.g.*, lakes), and potential interference from other transmission sources. In addition, these network planning and design tools are configured to account for the capabilities of the antennas and wireless equipment that are actually available to be deployed in the network.

To demonstrate the extent to which the KL Paper's reliance (and now the SR Paper's reliance) on the oversimplified propagation path loss model overstates the relative number of cell sites in rural areas, we presented results from our work with AT&T engineers to model hypothetical coverage only (ignoring capacity requirements) deployments using Atoll, which is the RF planning and design software that AT&T uses in the ordinary course of business to design and engineer radio networks. The results of this Atoll analysis confirm that the KL Paper's application of the simplified path loss model substantially overstates the relative number of cell sites that would be needed for a coverage-driven deployment in rural and suburban areas. For example, according to the KL Paper's analysis, an AWS (high frequency) deployment in a rural area would require about 6 times more cell sites than a Lower 700 MHz network, whereas the Atoll analysis found that a coverage-only, green-field AWS network would require at most 2.7 times as many cell sites as a Lower 700 MHz network in a rural environment. Similarly, according to the KL Paper's analysis, a 2.5 GHz deployment in a rural area would require about 14 times more cell sites than a Lower 700 MHz network. The Atoll model, applied as described above, found that, given the additional antenna technology flexibility at high frequency, a coverage-only 2.5 GHz network would also require at most 2.7 times as many cell sites as a 700 MHz network.

The SR Paper's response is that this Atoll analysis was an "apples-to-oranges" comparison because the Atoll analysis modeled a 700 MHz network using a 2x2 transmitter/receiver configuration, an AWS network using a 2x4 transmitter/receiver configuration, and a 2.5 GHz network using a 4x4 transmitter/receiver configuration, with a 30-watt transmitter for each transmit antenna. This response is not a valid criticism. As we fully explained in our prior paper, we used these various configurations because that is how each of these spectrum frequencies would be deployed in *the real world*. As we have explained, higher frequencies permit the use of much smaller antennas than lower frequencies, which permits more antennas to be used within a given amount of the antenna radome space in higher-frequency deployments. AT&T, for example, uses 2 Tx and 2 Rx base station configurations in its 700 MHz deployments and 2 Tx and 4 Rx base station configurations in its AWS deployments. Furthermore, Sprint has announced that it plans to deploy an 8x8 configuration for its 2.5 GHz deployment as part of Spark initiative (although our analysis used the more conservative 4x4 deployment). Ignoring these real-world configurations would provide a false picture of how these systems are deployed and would inaccurately predict the number of cell sites that would have to be deployed for each of the tested spectrum frequencies. The need to ensure valid comparisons does not justify an incorrect assumption that low- and high-frequency spectrum would be deployed using the same antenna configurations.[39]

In addition to the Atoll analysis, we presented the results of our own analytical calculations using the Okumura-Hata model to estimate path loss and hence cell size for Lower 700 MHz spectrum and the COST231-Hata model to estimate path loss and hence cell size for the 1900 MHz PCS spectrum. Using parameters that are well accepted by the industry, these models predict that a *green-field* lower 1900 MHz network designed solely for coverage (with no cell capacity or throughput requirements) would require only about 2.5 times more cell sites in rural areas, not more than 7 times more cell sites as predicted by the model used in the KL Paper. Sprint has not disputed our approach or our calculations. In addition, we would emphasize that this factor of 2.5 is valid only for green-field deployments. *In today's networks, green-field deployments rarely occur and the use of mixed frequency bands and overlay networks would require similar numbers of base stations at low-frequency spectrum and high-frequency spectrum*.

Third, we demonstrated in our prior paper that empirical evidence further confirms that the KL Paper's and the SR Paper's claim that high-frequency deployments require many times more cell sites than low-frequency deployments is incorrect. In particular, we presented the results of hundreds of thousands of miles of drive tests which collected various metrics for AT&T's and other operators' networks, including the number of cell sites deployed. These data cover the top 100 CMAs (which account for almost two-thirds of the U.S. population), and the vast majority of the geographic areas within these CMAs are "suburban" areas under the definition used in the KL Paper (U.S. Census Tract population density greater than 100 people per square mile and less than 10,000 people per square mile). According to these data, AT&T has more cell sites than Sprint along the drive test routes in 89 of the top 100 CMAs, and the same number of cell sites in one CMA. In the 10 CMAs where Sprint has more cell sites, it has at most 1.28 times more cell sites. These real-world data are thus wholly inconsistent with the estimates produced by the abstract and overly simplified methodology used by the KL Paper and the SR Paper, which, for example, predicts that Sprint would have many times more cell sites than AT&T.

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[39] The SR Paper's other argument is that the results of AT&T's Atoll analysis does "not comport with Sprint's real world network experience." SR Paper at 25. But the SR Paper does not divulge what this real world experience is, relying instead on its flawed hypothetical analyses. Further, we note that the Atoll-based analysis uses the uplink-dictated link budget to determine the equivalent downlink signal strength at the cell-edge. Hence, the downlink coverage analysis uses 2.1 GHz carrier frequency for the AWS band. The proximity of the 2.1 GHz band to the 2.5 GHz band and the use of more transmit antennas for the 2.5 GHz band compared to the 2.1 GHz band largely explains the final outcome of a similar number of sites for 2.1 GHz and 2.5 GHz. Again, this Atoll result is quite logical and in line with engineering principles. With respect to a comparison of the Atoll results with Sprint's experience, Sprint uses PCS spectrum which provides a less relevant and less accurate comparison because the spectrum bands are farther apart (1900 MHz vs. 2.5 GHz). Furthermore, although Sprint's Spark may use more antennas, Sprint might not yet be using more antennas at this time in the 2.5 GHz band.

The SR Paper's response is that AT&T's drive test data do not account for coverage. Specifically, the SR Paper hypothesizes that it has fewer cell sites because it has less coverage in the areas where the drive tests were conducted. But the SR Paper provides no evidence to back up this hypothesis. Furthermore, in our view, it is highly unlikely that Sprint has significant coverage gaps in the drive test areas, which comprise the top 100 CMAs, where Sprint has been building out its networks for more than a decade. To drive this point home, these drive test data show that AT&T has more cell sites than Sprint in each of the top 10 CMAs, where Sprint has clearly had maximum incentives to ensure comparable coverage to AT&T during the last decade. Additionally, Sprint's online coverage maps purport to cover these top 10 CMAs.

We also note that these drive test data refute the theoretical modeling described in a recent letter by T-Mobile. In this letter, T-Mobile describes a "network design study for the Dallas, Texas Basic Economic Area (BEA)" performed by T-Mobile's "internal national RF planning team."[40] This analysis purports to show that T-Mobile could serve Dallas with far fewer cell sites if it were to use Lower 700 MHz spectrum rather than the AWS spectrum it is currently using. But real world empirical evidence from the drive test data described above refutes this theoretical modeling assertion. If T-Mobile's analysis were correct, one would expect that AT&T – which serves Dallas using Lower 700 MHz spectrum – would have fewer cell sites than T-Mobile in Dallas. But these drive test data show that AT&T actually has about 150 more cell sites than T-Mobile in the Dallas-Fort Worth CMA. Absence of the specification of critical assumptions (*e.g.*, number of receive antennas at the base station, relative transmission power levels, receive threshold levels, etc.) precludes proper evaluation of the T-Mobile paper's conclusions. However, we note that the T-Mobile analysis assumes an unrealistic coverage-driven deployment scenario and ignores capacity-driven deployments, and it ignores the impact of SINRs by focusing solely on absolute signal levels.

4.2 The New Errors Introduced By Sprint's Latest Submission

The SR Paper attempts to account for the cost of spectrum licenses in its analysis of the relative costs of low- and high-frequency deployments (which is then equated to the relative value/utility of spectrum). As the economic testimony in this proceeding predicted, the incorporation of spectrum license costs into the analysis has an immense impact on the results. For example, for suburban areas, the KL Paper's original analysis – which ignored these costs – predicted that a 2.5 GHz deployment would cost about 7 times more than a Lower 700 MHz deployment, but after accounting for costs, the SR Paper's new analysis predicts a 2.5 GHz suburban deployment would cost only about 1.9 times more than a Lower 700 MHz deployment. Given how sensitive the SR Paper's new model is to the cost of spectrum licenses, it is critical that those spectrum costs reflect those that would be incurred in the real world. The SR Paper's analysis, however, substantially understates those costs.

The SR Paper's analysis of rural deployments vividly illustrates this problem. This analysis assumes that a provider can purchase Lower 700 MHz spectrum in a rural area for $0.60 per

[40] McDiarmid Decl. ¶ 12.

MHz-POP. The SR Paper does not state how it computed this figure or which "rural" areas were used to derive it. And recent evidence appears to contradict it. For example, in an investor presentation, T-Mobile estimated the prices (in terms of MHz-POP) for various 700 MHz secondary market transactions and auction purchases. For example, T-Mobile estimates that recent secondary market transactions for Lower 700 MHz spectrum ranged from about \$1.57/MHz-POP up to \$4.29/MHz-POP. Similarly, T-Mobile estimated that the 2008 auction prices for Lower 700 MHz spectrum ranged from \$1.47 (impaired A-Block) up to \$3.15/MHz-POP.[41] All of these prices exceed \$0.60/MHz-POP.

Although the SR Paper does not explain how it derived \$0.60/MHz-POP for Lower 700 MHz spectrum, it appears that T-Mobile might have discounted the market prices for spectrum to account for relatively less demand for spectrum in rural areas. But this approach is overly simplistic, because, for many rural areas, service providers cannot purchase spectrum only for only that area, but must pay higher prices that reflect the non-rural areas also covered by that license. For example, 700 MHz spectrum licenses are generally available at the EA and CMA levels, which typically cover very large geographic areas with widely variable population densities. The price of these spectrum licenses will thus generally be driven by the high demand for spectrum in the more densely populated areas covered by the license, so that any real world spectrum purchases will necessarily be made at these much higher prices, not at hypothetical rural-only prices computed by the SR Paper. By understating the price of spectrum licenses in this way, Sprint's analysis substantially understates the extent to which any differences in the deployment costs of low- and high-frequency spectrum will be offset by differences in spectrum license costs.

As to the suburban analysis, the SR Paper assumes that spectrum licenses for Lower 700 MHz spectrum cost only \$2.00/MHz-POP. Again, the SR Paper greatly understates the costs of spectrum licenses, thus overstating cost differences for low- and high-frequency deployments. The SR Paper uses the same definition of suburban as the KL Paper, which is any area with a population density up to 10,000 people per square mile. As we demonstrated in our prior paper, this definition encompasses areas in large cities, such as the area where Penn Station and Madison Square Garden are located in New York City, about half of downtown Washington, D.C., Newark Airport, and numerous other urban or otherwise densely populated areas. In these urbanized areas, it is our understanding that spectrum licenses cost far more than \$2.00/MHz-POP. For example, an analysis submitted by economists in this proceeding shows that even for areas with population densities of between 618-4,290 people per square mile, Lower 700 MHz spectrum in Auction 73 sold for more than \$4.00/MHz-POP, which is nearly

[41] T-Mobile Presentation, "T-Mobile US, Inc. – A-Block Spectrum Transactions," *available at* http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9NTI4NzY1fENoaWxkSUQ9MjE2MzQyfFR5cGU9MQ==&t=1 (slide 9).

twice the amount that the SR Paper assumes.[42] By understating the cost of spectrum licenses in this way, the SR Paper also understates the extent to which the higher price of low-frequency spectrum licenses offsets any potential savings in deployment costs of high-frequency spectrum.

[42] *See* Reply Declaration of Mark A. Israel and Michael L. Katz, *Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings* (Jan. 7, 2013), ¶ 20-21, attached to Reply Comments of AT&T Inc., *Policies Regarding Mobile Spectrum Holdings,* WT Docket No. 12-269 (Jan. 7, 2013).